Thick Silicon Detectors for HXT

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Overview

- Issues with silicon for hard X-ray detection
- Potential Advantages
- Development of thick, room temperature detectors
- Detectors with excellent energy resolution
  - Active Pixel Sensors
  - Silicon Drift Detectors
  - Controlled Drift Detectors
- Wafer Bonding Technology
- Simulated Performance

Advantages/Disadvantages (Si vs. CZT)

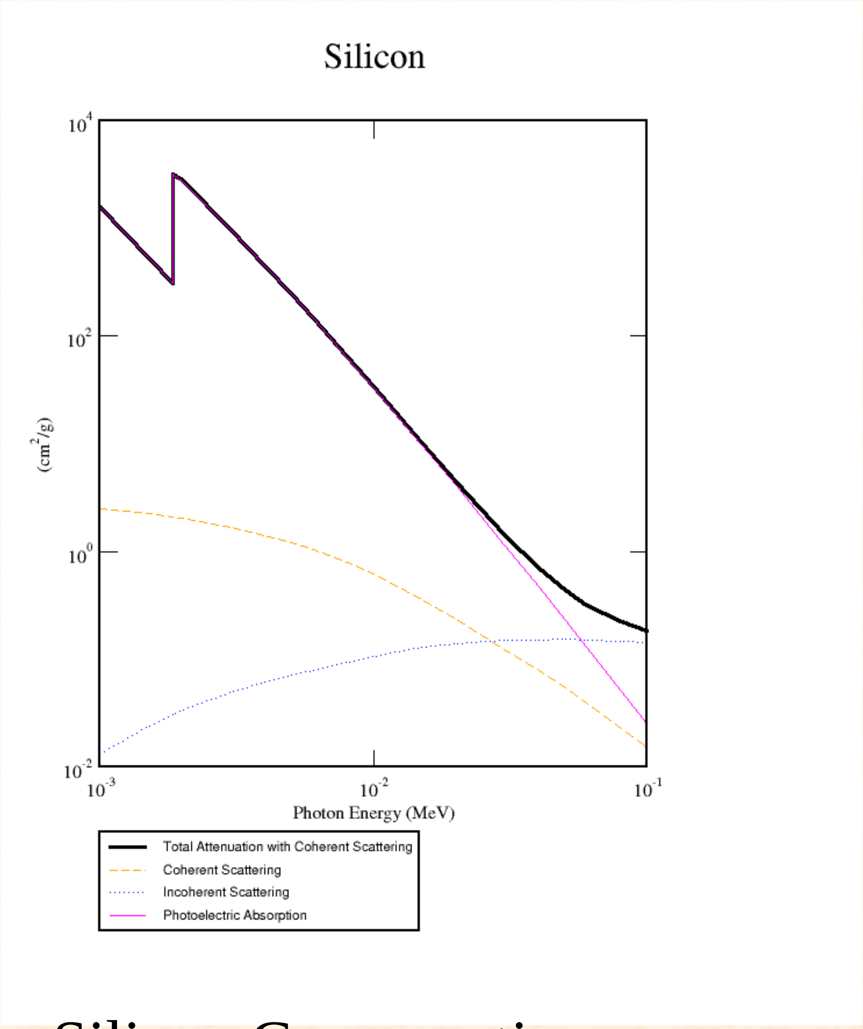
Advantages

- **Better Energy Resolution**
- **Better Imaging (smaller pixel size)**
- **Reduced Background (use Compton scatter to limit X-rays to direction from HXT mirror at higher energies)**
- **Polarization (above 40 keV)**
- **Better overlap with Soft X-ray imager**

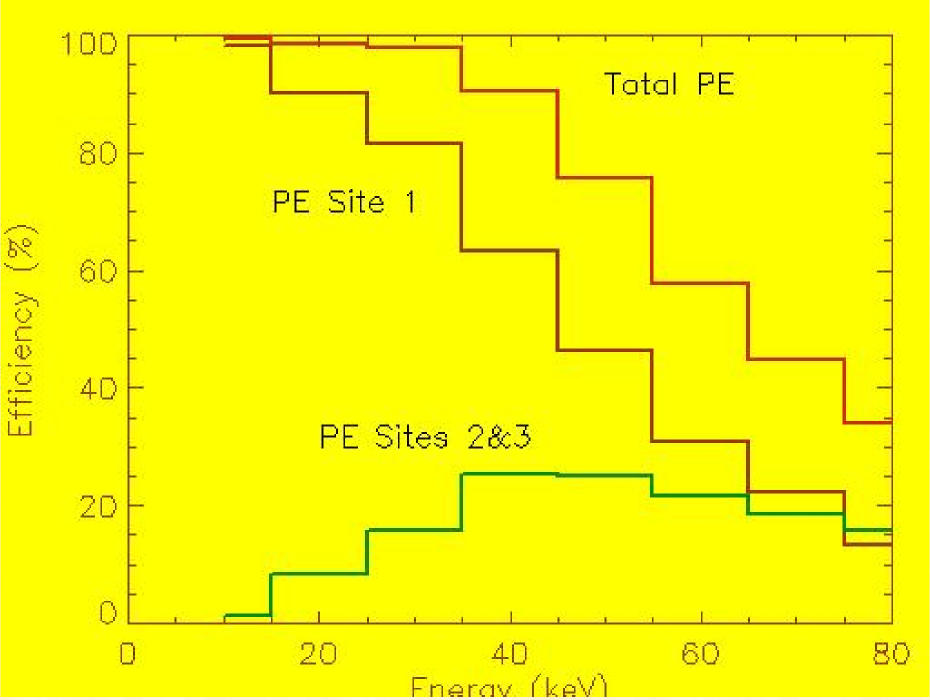
Disadvantages

- **Lower efficiency above 40-50 keV**
- **More detectors required**

Silicon cross-sections/efficiencies

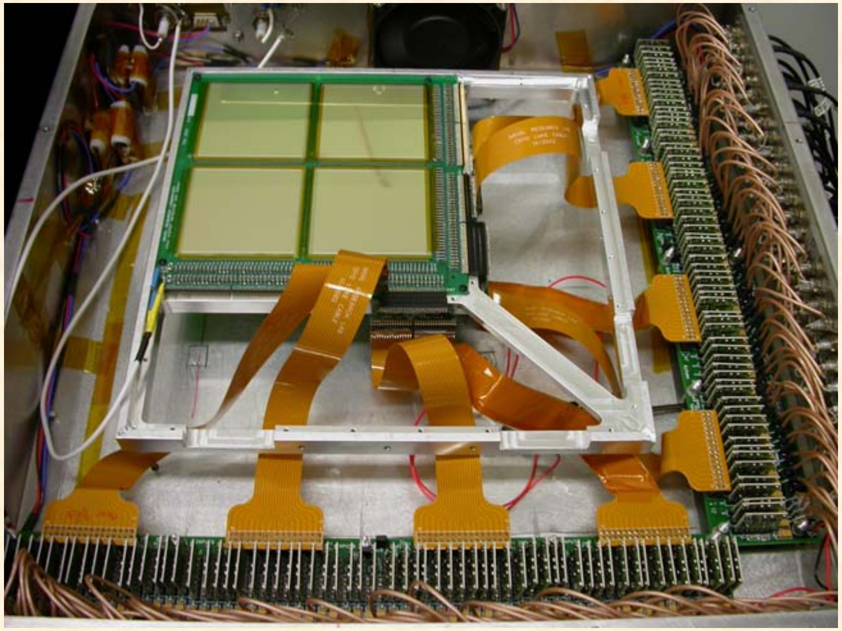


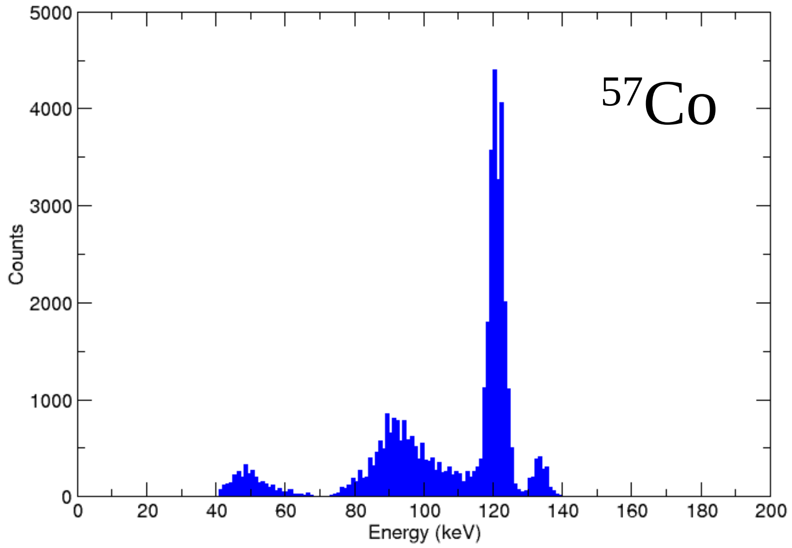
Silicon Cross sections

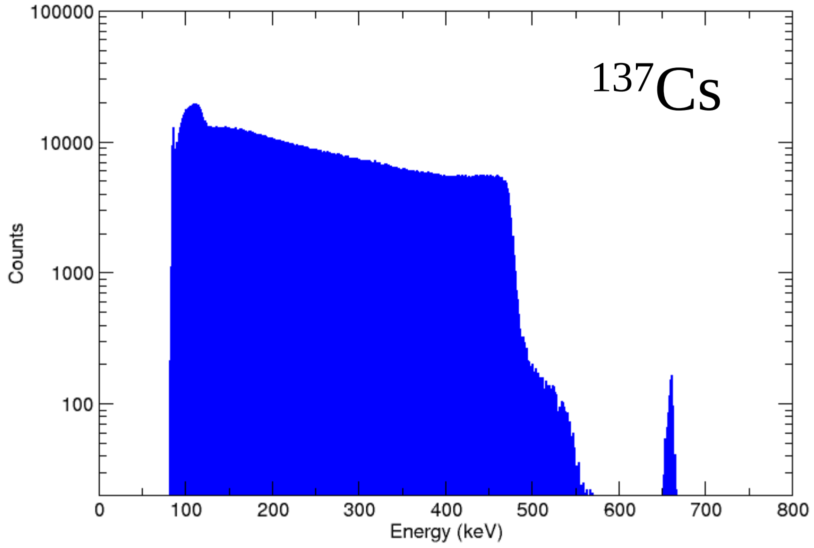


Efficiency vs. Energy for photoelectric and Compton-PE interactions (2 cm thick silicon)

2 x 2 Array Detector Performance

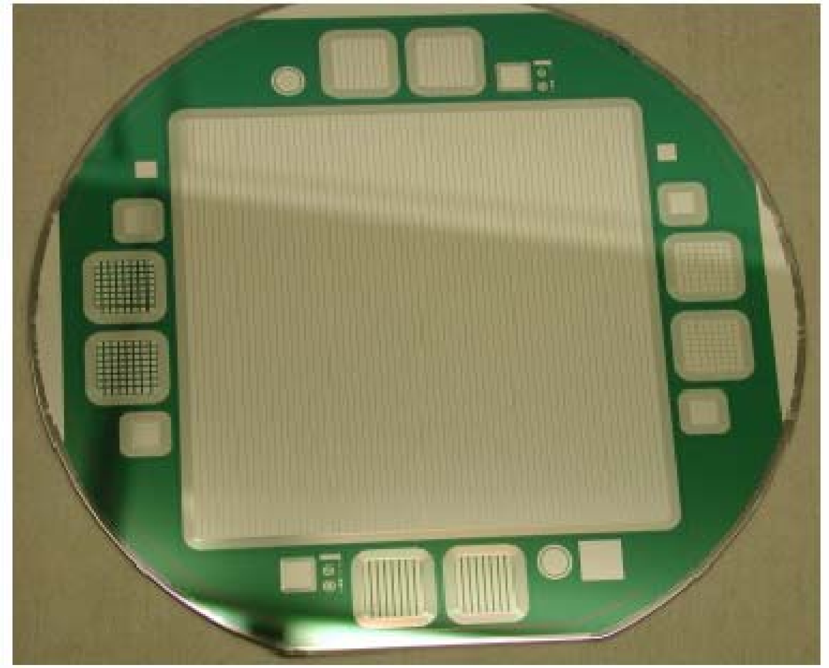


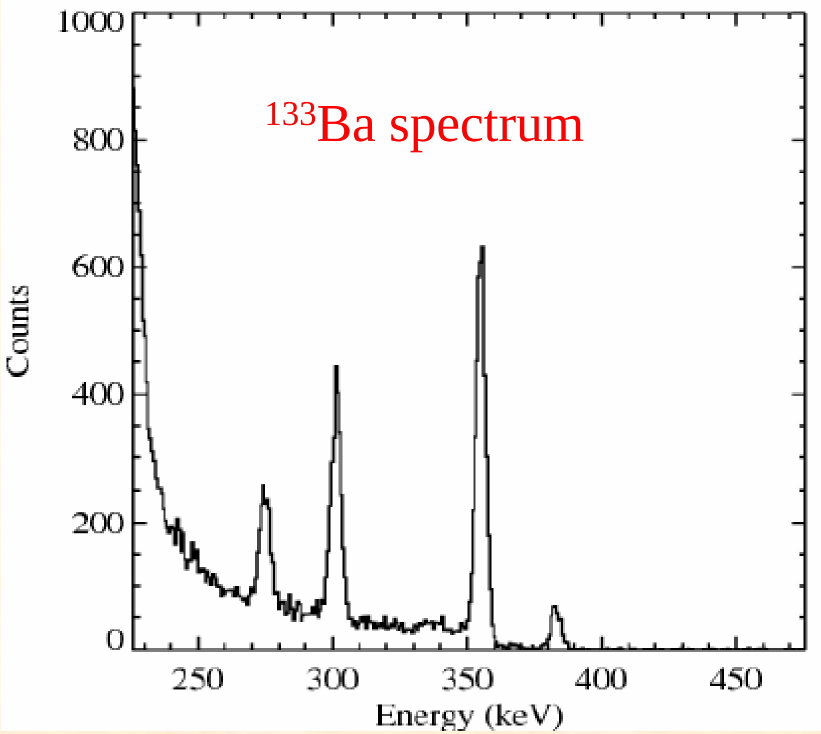




- Test 2 x 2 tray with laboratory electronics
- Spectra at right for 2x2 array for ^{57}Co (full array) and ^{137}Cs (single daisy chained strip)
- Both spectra show good room temperature energy resolution of 4.5-5 keV FWHM

Detector from150mm dia. wafer



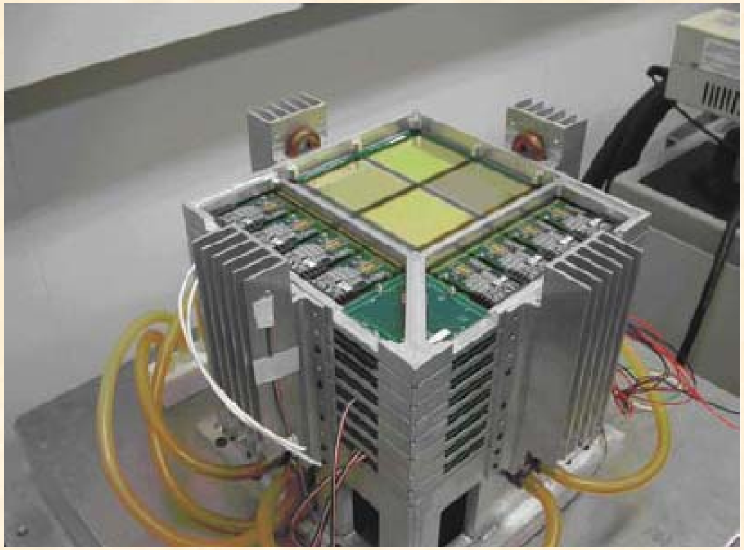


Room temperature spectrum: 4 keV resolution

This is limited by electronics—expect 2-2.5 keV with thicker detector and cooled to 0 to 10 ºC

DTRA Prototype Compton Imager

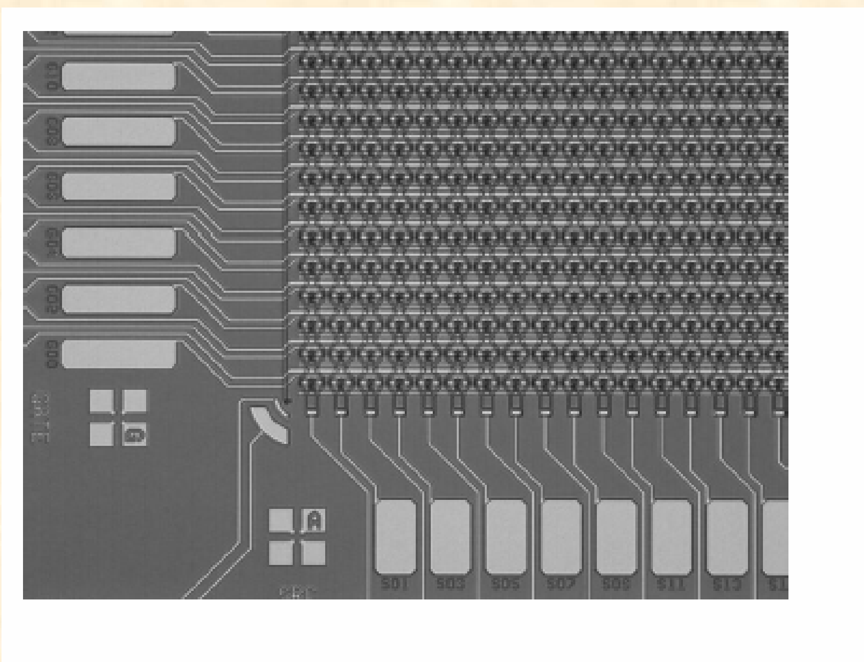
Single tray of a 2 x 2 array of 63mm x 63mm x 2mm-thick orthogonal strip detectors. Each detector has 64 strips per side read out be ASICs.

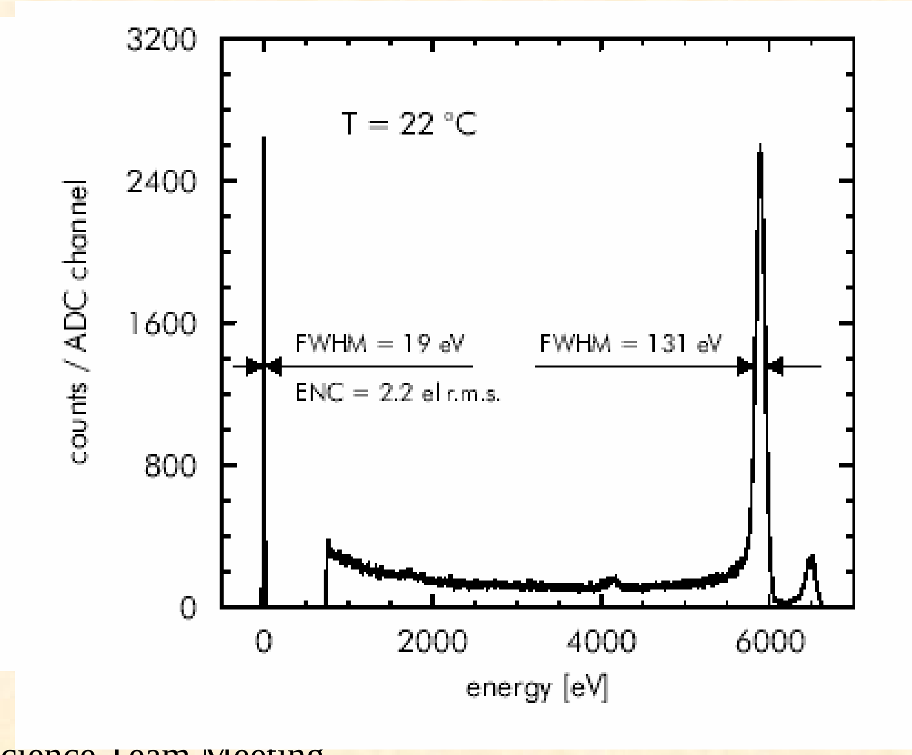


Eight layer prototype unit. The detector can be housed in a cooler to test performance down to –40C.

DEPFET Active Pixel Sensors

Fully depleted CMOS sensor with tens of microns pixel size
Room temperature operation
Excellent energy resolution
Sparse low-power readout upon event detection
May enable electron tracking at few hundred keV energies
Under development for XEUS (300-500 micron thickness)





Controlled Drift Detector

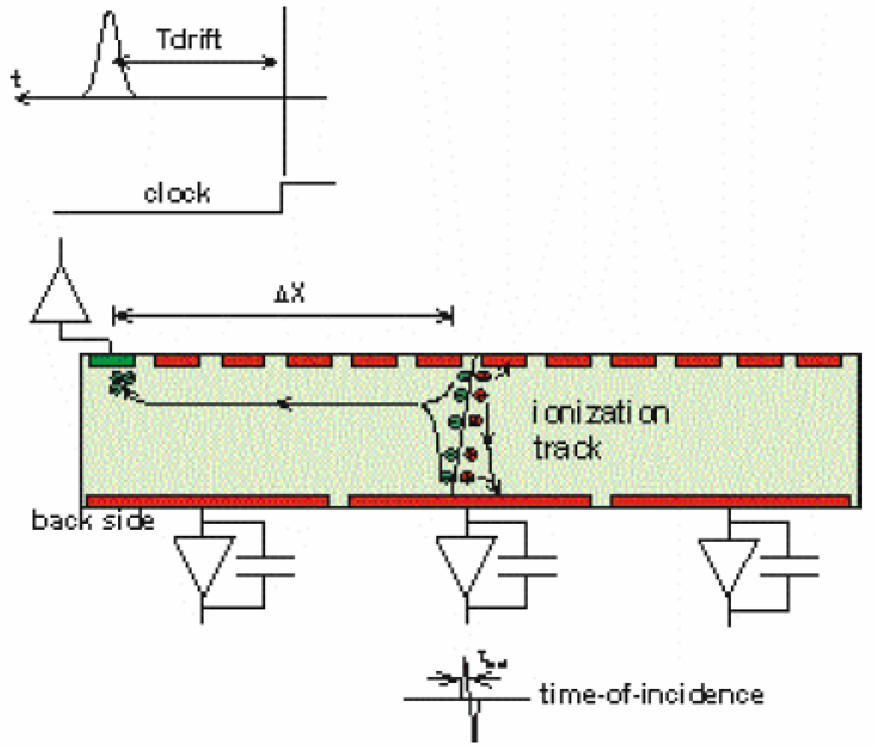


Fig. 3 Scheme of principle of a Controlled-Drift Detector instrumented to measure the induced signal on the back side.

Under development by MPE/PN Sensor and Politecnico Milano

"Development of Controlled Drift Detectors and their application to Compton Imaging" A. Castoldi and C. Guazzoni, XCI Congresso Nazionale Societa Italiano di Fisica, 26 Sept – 1 Oct 2005

Multi-Linear Silicon Drift Detectors

120 micron pixels

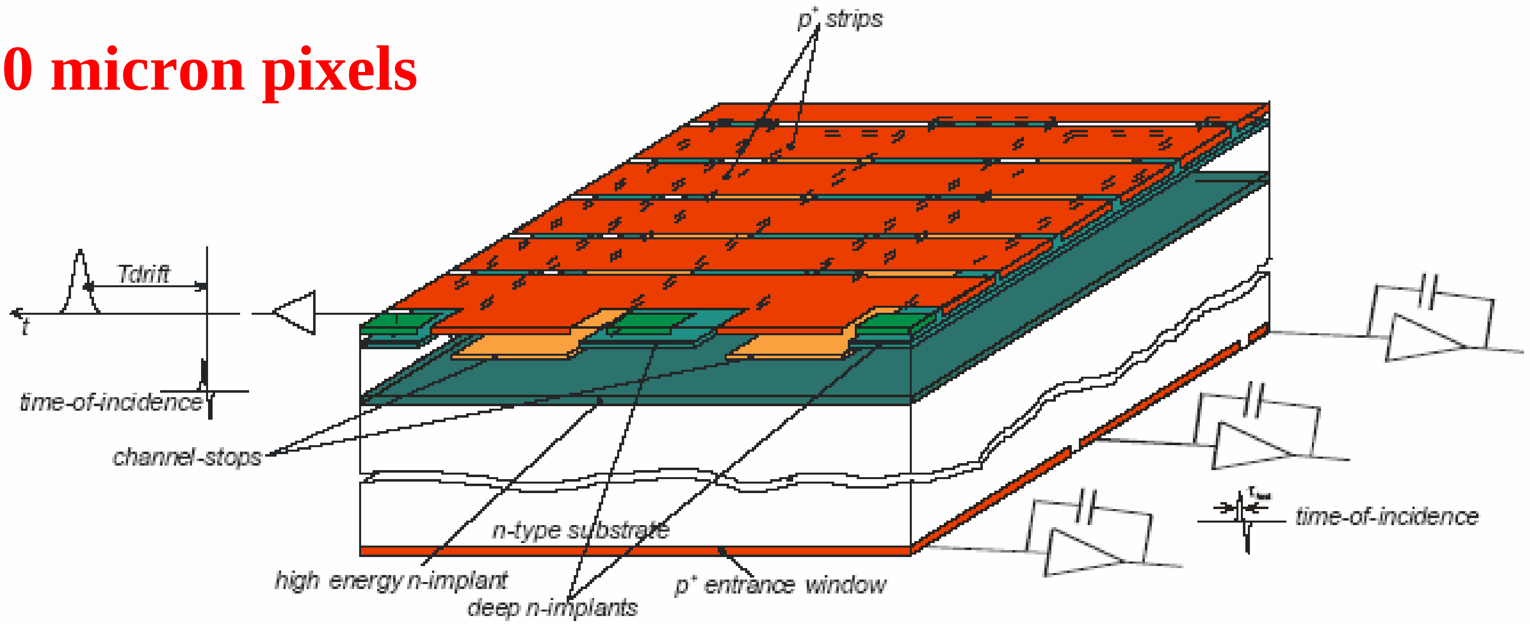


Fig.2. 3D schematic view of the Self-Triggered Multi-Linear Silicon Drift Detector. The high energy n-implant is used to locate the potential minimum for the electrons close to the implanted detector surface. The p+ strips on the back side are instrumented to measure the signal induced by the generated charge.

"Self-triggered Multi-Linear Silicon Drift Detectors", A. Castoldi et al., IEEE Conf. Record p. 1236-1240 (2004)

Drift Detector Spectrum

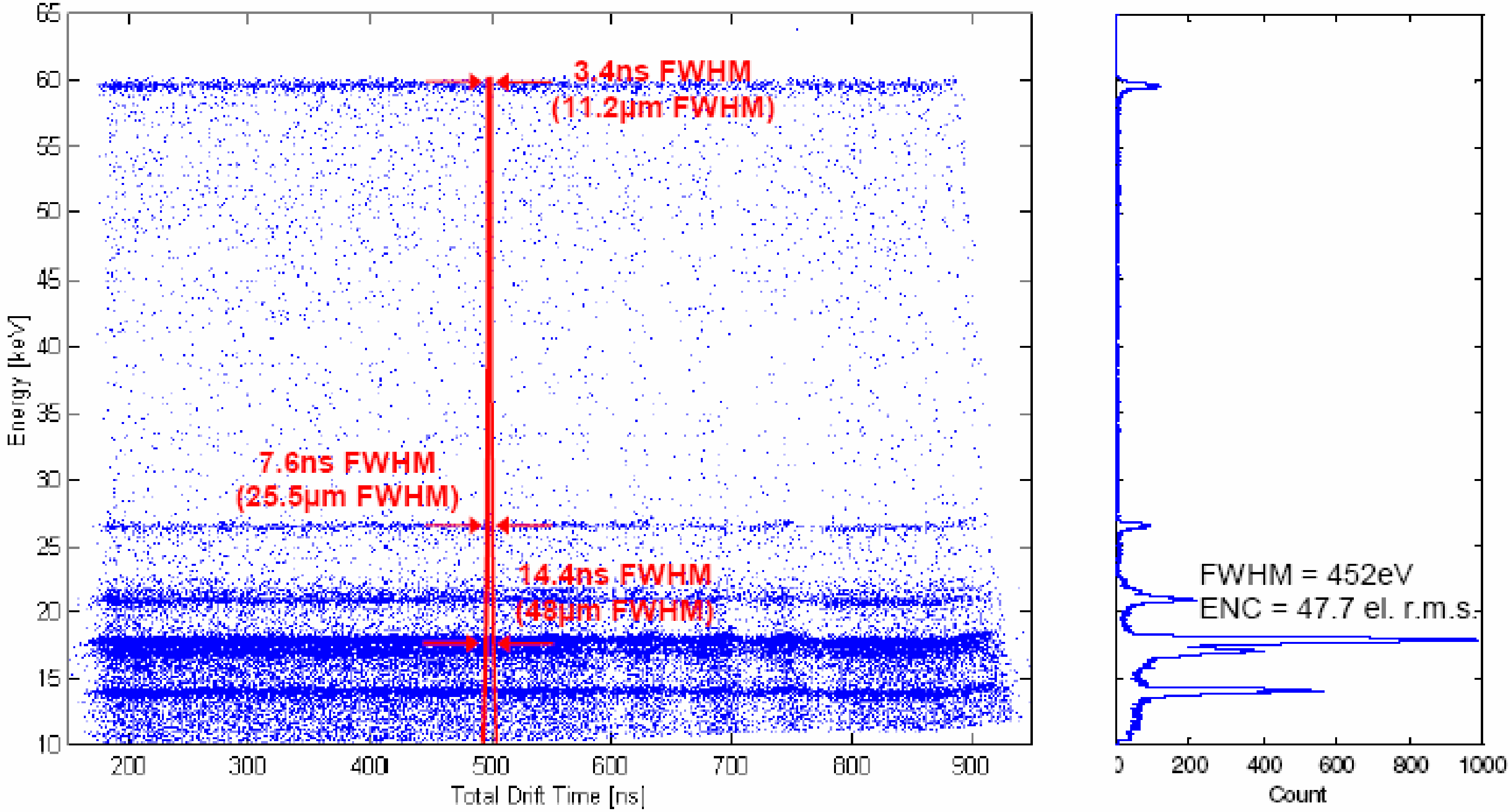
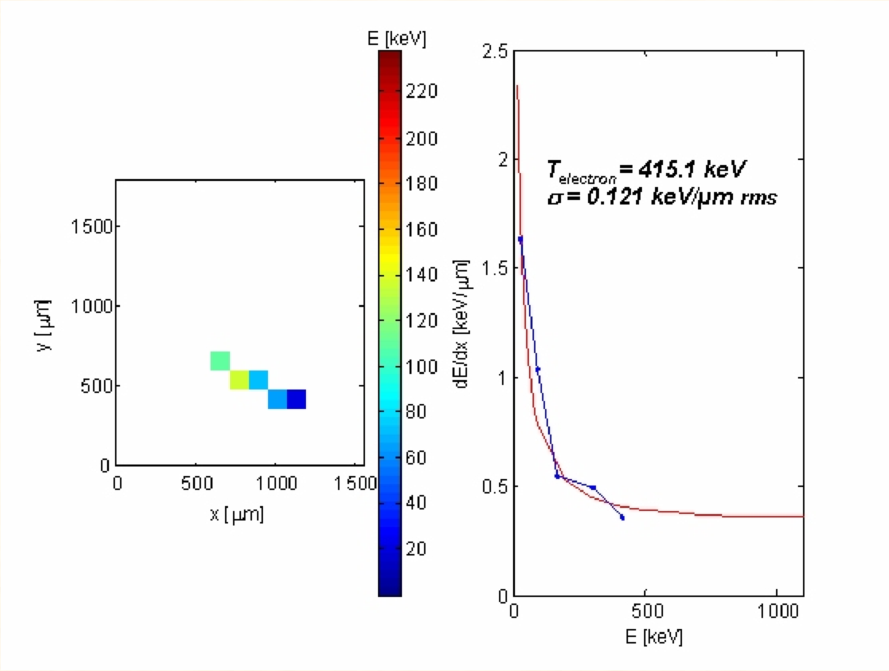


Fig. 7. Scatter plot energy vs. drift time of the detected events at one channel when a ^{241}Am source irradiates the detector. The red line on the scatter plot and the relative labels indicate the achievable time (and, hence, position) resolutions measured at the different energies. The inset on the right end shows the total distribution of the event energies (i.e. the spectrum of the ^{241}Am source collected by the whole channel active area).

Low-Energy Electron Tracking in Silicon Detectors

Tracking the Compton scattered electron enables reducing the Compton cone to an arc segment and thereby reducing the incident direction of the gamma ray. It also eliminates background events and improves the sensitivity and a Compton Imager

The figure on the right shows the track of a 415 keV electron that was generated by the Compton scatter of a 1.33 MeV gamma ray in a Controlled Drift Detector (CDD)—a silicon detector with 120 micron pixel readout. These detectors also have excellent energy resolution and low threshold capabilities (< 5 keV).

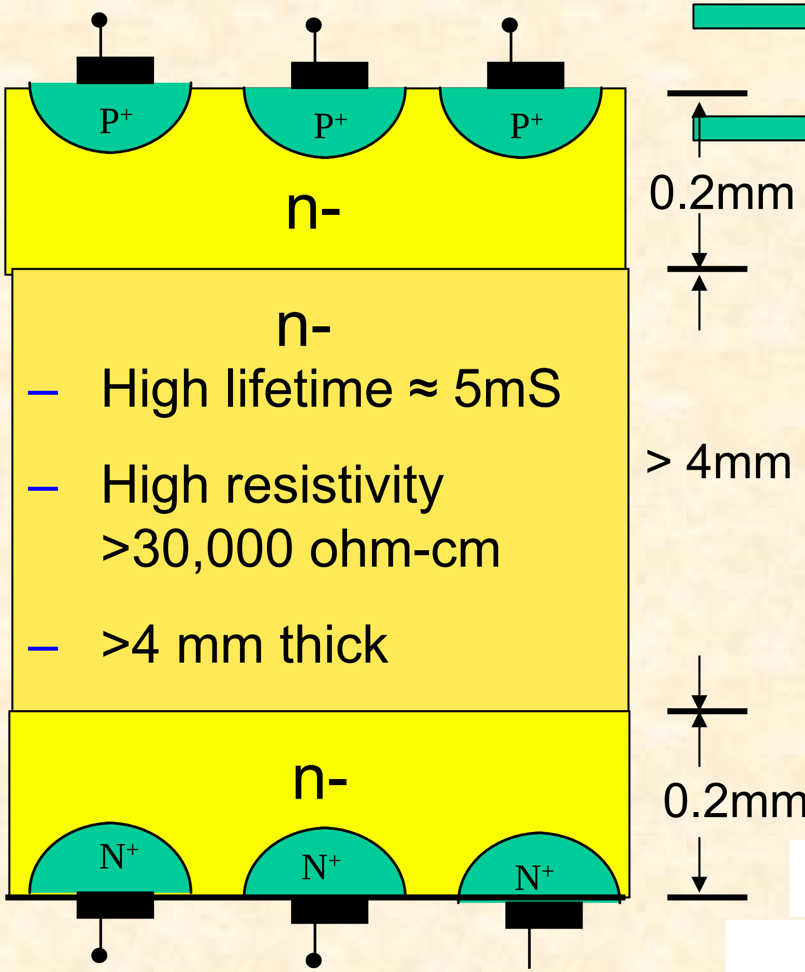


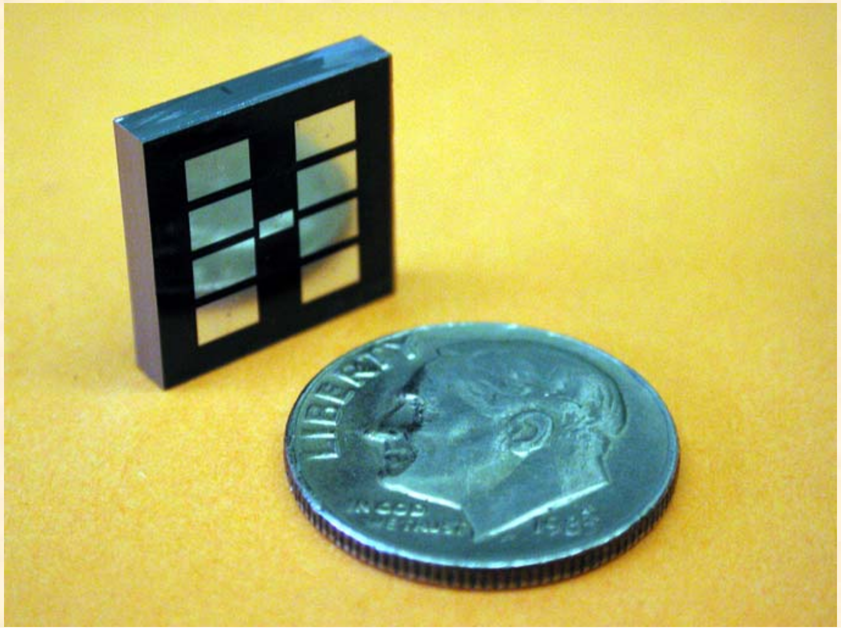
Track of a 415 keV electron

Wafer Bond High Voltage Silicon

(1) **>20kV Power Switch**

(2) **High Voltage Pulsed Power Switches**

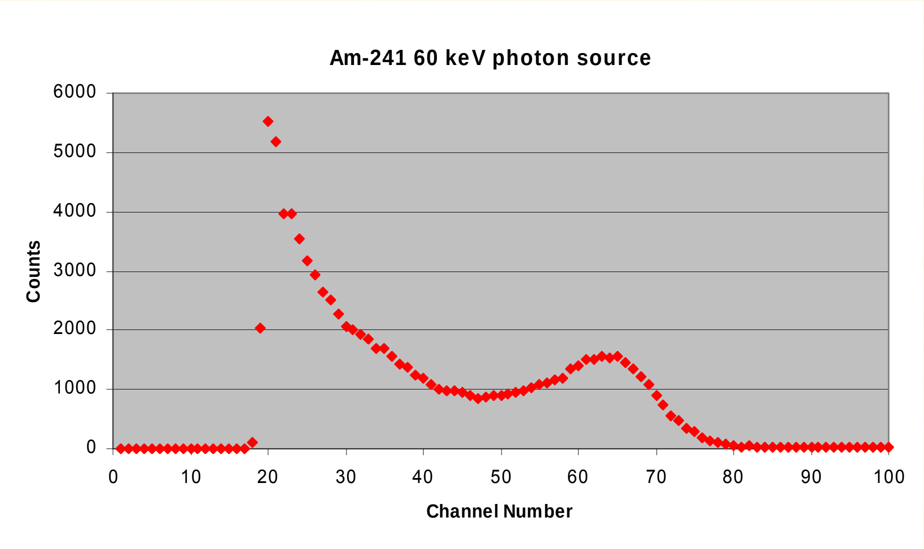


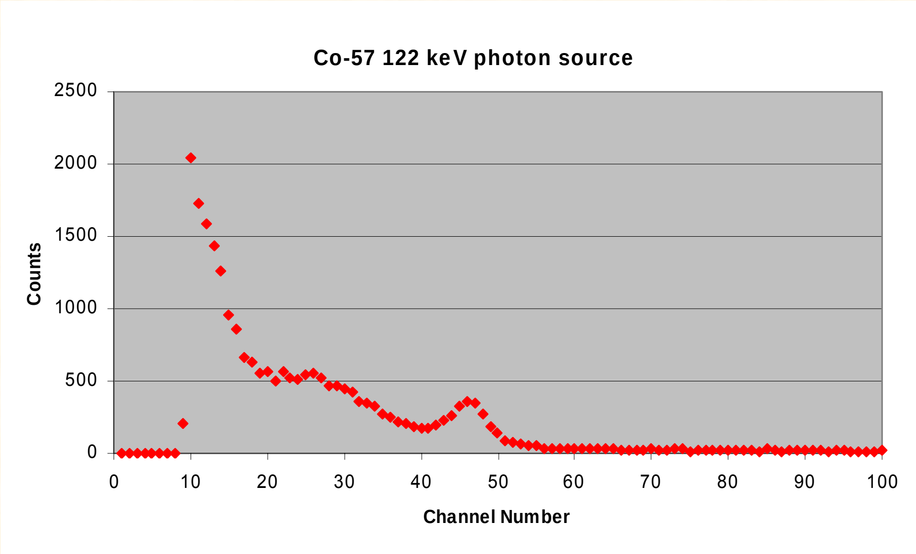


2.4mm thick wafer bonded power switch

Low Leakage Current

Gamma Ray Spectra

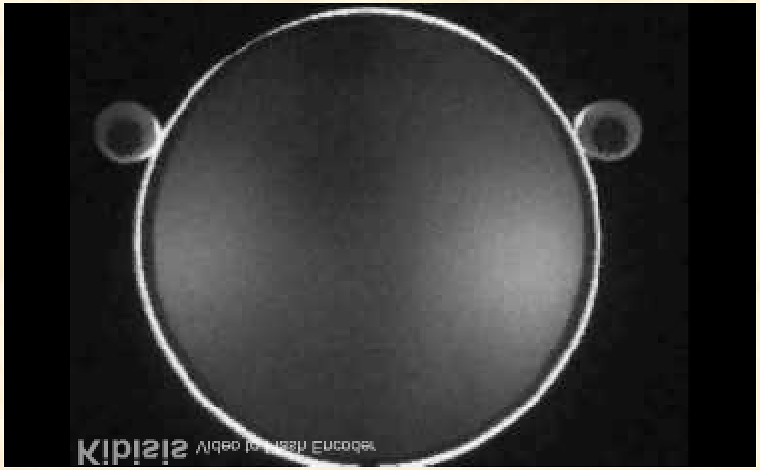




- The spectra show that wafer-bonded power diodes are gamma ray detectors
- Design was not at all optimal as gamma ray detector: 100s of Amps vs nanoAmps

Wafer Bonding: the Movie

Click to play



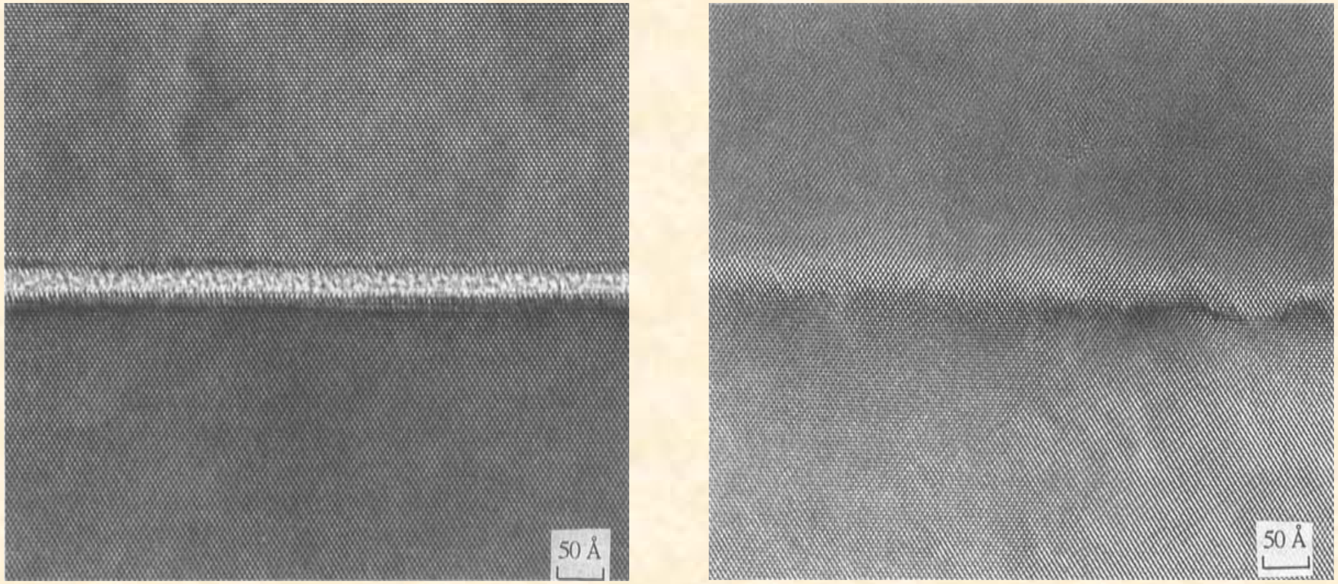
Click to play

- Movies show infrared transmission through both wafers.
- Newton's rings motion visible as separation of wafers decreases
- Contact region spreads on its own
- Happens at room temperature
- Process followed by low temperature anneal.
- NRL Patents (Code 6880):
  - Navy Case 96318, IEB Approved September 16, 2004.
  - U.S. Patent issued February 27, 2001.U.S. Patent #6,194,290.
  - U.S Patent issued November 28, 2000. U.S. Patent # 6,153,495.
  - U.S. Patent issued August 14, 2001. U.S. Patent # 6274892.

Wafer Bonding Process

Partial Device Fab
↓
Thin / CMP Backsides
↓
Clean / H-Terminate
↓
Align / Bond
↓
Anneal (≈400°C)
↓
Saw / Package / Test

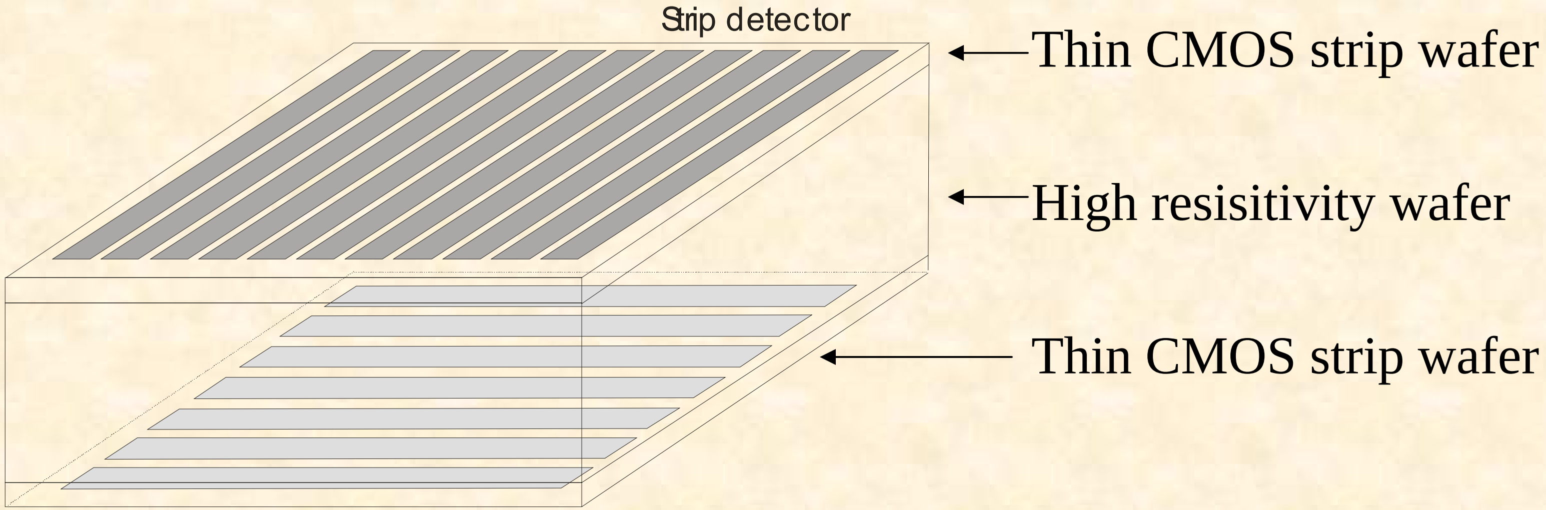
Schematic of wafer-bonding process



Transmission Electron Micrograph of a hydrophilic wafer bond (Left) and a hydrophobic wafer bond (Right).

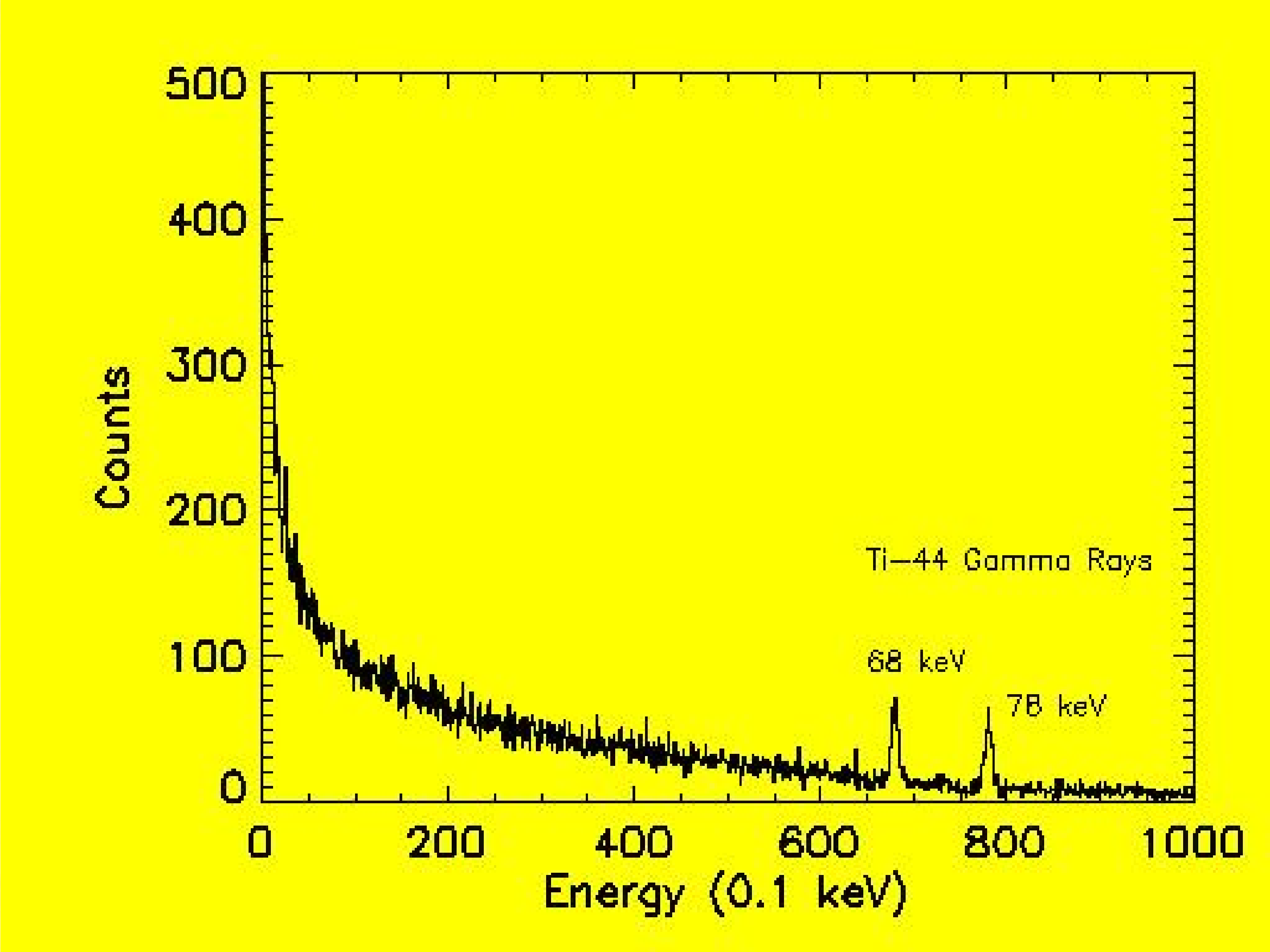
Thick Strip detector

3-layer device



- Thicker detectors improve efficiency of detecting Hard X-rays and gamma rays
- Bond Active Pixel Sensors or Controlled Drift Detectors to thick (~ 5mm) intrinsic silicon wafers??

Simulated Ti-44 Spectrum



Summary

Thick silicon detectors are an option for HXT using pixellated and/or drift devices and if they can be integrated into a wafer-bonded device.

Potential advantages:

- Better energy and imaging resolution
- Polarization sensitivity
- Reduced background